Appendix E

AM Subjective Evaluation Program and Platform

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AM Subjective Evaluation Program and Platform

1. Introduction

The AM Subjective Evaluation Program was designed to demonstrate that (a) consumers judge the audio quality of iBiquity's AM IBOC system as qualitatively better than currently available AM analog reception and (b) the AM IBOC system operates with minimal impact to existing AM audio quality. For AM testing iBiquity has worked closely with the Advanced Television Technology Center (ATTC), Xetron, Inc. and Dynastat,Inc. to execute the AM portion of the test program for NRSC evaluation.

This appendix summarizes the methodology used in subjective evaluations, and reviews the process by which sound samples were generated, tested and analyzed. For information concerning specific experimental procedures and methodologies, refer to Appendix F - Dynastat - Methods and Procedures for AM Audio Testing**.**

The Subjective Evaluation Program was divided into two areas: (a) field and lab performance testing and (b) field and lab compatibility testing. In order to complete subjective evaluation of all audio material, six experiments were conducted at Dynastat. Each experiment lasted approximately 1½ hours, including participant training, screening and testing. Table 1 lists these experiments including the material that was tested and their corresponding NRSC test, where applicable.

Table 1: Experiments conducted at Dynastat

Experiment	Material Tested	NRSC Test
1	AM Laboratory compatibility	E&H
2	AM Laboratory compatibility	E&H
3	AM Laboratory performance	B, C, D
4	AM Field compatibility	FC/C
5	AM Field performance	FP/B
6	AM Field performance	FP/B

2. Sound Sample Generation

2.1 Source material and Pre-processor settings

Original source material used for all AM subjective testing was taken from NRSC FM Test material. Thirty-four sound samples were selected for impairment testing. These consisted of a subset of classical and rock samples, as well as a subset of speech samples from FM SCA tests and voiceover commercials recorded at WTOP. Sound samples were grouped together in equivalent "families" (i.e., samples exhibiting the same characteristics) so that they could be used interchangeably in subjective experiments. As with FM testing, because certain experiments required participants to listen to 200+ sound samples, it was felt that severe listener fatigue would occur if the same sound samples were repeated many times. Therefore, where appropriate, equivalent sound samples were used to minimize the effects of listener fatigue. However, when substituting equivalent sound samples, all care was taken to use the same cut within a specific condition.

For AM analog and digital recordings, Orban pre-processor factory settings were used. Exhibit 1 is a complete listing of sound samples and their associated pre-processing settings.

2.2 Lab Test Audio Samples

Compatibility samples were generated at Xetron, and performance samples were generated at ATTC in accordance with the NRSC test program. Sound samples were subsequently sent to Dynastat for evaluation. Editing and leveling of all samples were performed identically for lab and field testing. (See Exhibit 2 for editing and leveling guidelines used for both lab and field recordings.) Sample failures were defined as those audio segments in which (a) noise created by the interferer was stronger than the signal, so that the signal was no longer audible or editable with editing software and (b) the interfering signal was stronger than the primary signal such that the interferer was heard clearly, but the signal of interest was no longer audible or editable. Sample failures were archived, but were not sent to Dynastat for testing.

2.3 Field Test Audio Samples

2.3.1 Compatibility Samples

Field compatibility recordings were made using the iBiquity Field Test Platform over NRSC test radios. Data was collected at multiple locations for each of the host, 1st adjacent channel and 2nd adjacent channel compatibility tests. NRSC test radios were tuned to either the IBOC host or to an analog station adjacent to the IBOC station. Simultaneous recordings of all four radios were made while the test IBOC station's digital carriers where switched on and off in a prescribed pattern: DAB On for 30 seconds, followed by DAB Off for 30 seconds, repeated for a total of 10 cycles. The test team recorded the test receiver audio using a Tascam DA-98 multi track digital recorder, keeping records of the recorder's SMPTE time codes corresponding to the DAB On/Off periods.

During Hybrid AM transmission, the IBOC exciter must limit the analog host modulation bandwidth to 5 kHz or less in order to be compatible with the IBOC DAB signal. Normally, when the IBOC exciter is switched to DAB Off mode, the host bandwidth remains low pass limited to 5 kHz. However, as instructed in the NRSC's IBOC Field Test Procedures – AM Band, the test team increased the DAB Off analog transmission bandwidth to the full 10 kHz (with NRSC pre-emphasis) wherever possible. Table 2 lists the compatibility test stations, the corresponding IBOC interferer and the DAB Off modulation bandwidth of the IBOC host. Note that in the case of WTOP procedural changes made it possible to use a 10 kHz DAB Off host modulation bandwidth in later tests, including those for WFAI, WLPA and WDAS.

Table 2: Field Compatibility Stations

Compatibility Test	**Desired Station**	**IBOC Interferer**	***DAB-OFF* IBOC Host Modulation BW**	**Comments**
Host	KABL	-	5 kHz	
Host	WTOP	-	5 kHz	
Host	WWJ	-	10 kHz	
1st Adjacent	KAHI	KABL	5 kHz	
1st Adjacent	KESP	KABL	5 kHz	
1st Adjacent	WARK	WTOP	5 kHz	
1st Adjacent	WFAI	WTOP	10 kHz	
1st Adjacent	WLPA	WTOP	10 kHz	
2nd Adjacent	KCTY	KABL	5 kHz	Spanish language station: no usable samples
2nd Adjacent	WDAS	WTOP	10 kHz	
2nd Adjacent	WEOL	WWJ	10 kHz	
2nd Adjacent	WKHM	WWJ	10 kHz	

Field audio was converted from DA98 to wave files for the purpose of editing. For compatibility tests, audio was recorded with IBOC DAB being turned on and off at 30-second intervals. For each location, test samples were created by choosing 2 comparable 15-second segments (one with IBOC off, and one with IBOC on). Based on time-code records, each 30-second DAB Off or DAB On section of all of these wave files was edited and copied to new wave files. This process resulted in at least one DAB Off and one DAB On wave file for each location, at each radio station, and on each radio. When selecting comparable DAB Off and DAB On samples for each condition (location, radio station, and radio), several criteria were used:

- samples were approximately 15 seconds long
- The DAB Off and DAB On samples were approximately the same length, within 0.5 seconds of each other.
- The programmatic content of the DAB Off and DAB On samples was as similar as possible.
- The musical characteristics of the DAB Off and DAB On samples were as similar as possible.

Each identified segment was copied into a new wave file. Wave files were named and edited to envelope the beginning and end of the file. Sound sample editing was performed identically for each radio. Finally, all of the wave files were leveled. Exhibit 2 - “Procedure for Editing and Leveling Sound Samples” contains additional details regarding the leveling process.

2.3.2 Performance Samples

Exhibit 3 describes in detail how performance samples were chosen for the AM test program. Samples included:

- Significant 1st and 2nd adjacent channel interference

- Whole or partial shielding by Grounded Conductive Structures (GCSs)
- Proximity to powerlines
- Powerline re-radiation of the AM signal
- Electromagnetic interference (EMI)
- Occurrences of IBOC audio mode transitions from enhanced to core and from digital to analog
- Skywave interference (night performance)

3. Participant Testing

All subjective evaluations were conducted at Dynastat. Each experiment included 40 listeners, stratified both for listener gender and age. All participants were trained prior to testing and screened twice. Participants were given a pre-screening test designed to eliminate those listeners who could not easily hear impairments. Second, a post-hoc analysis was conducted on all listeners to determine the reliability of results for each listener. Although listeners were drawn from the general public, they were both trained to detect impairments and capable of discriminating impaired audio from unimpaired reference material.

Experiments were conducted in acoustically designed sound rooms which contained minimal environmental noise. Approximately 200 sound samples were presented to participants during each experiment. Participants listened to all samples over Tannoy Reveal speakers and recorded their responses directly to a work station.

As in the FM test program, methodology for all experiments was the Absolute Category Rating Method (ACRM). In ACRM participants judge sound samples on an individual basis, using an implicit reference to judge the quality of the sound sample. Within a particular ACR experiment participants generally hear a variety of sound-samples that may differ on several dimensions. Their mission is to give a statement of “overall quality”, taking into consideration the variety of audio elements that may be present.

4. Analysis of Data

At the conclusion of each experiment, Dynastat delivered results in the form of Excel worksheets to iBiquity. One worksheet included the listeners that were kept in the final data set. The other worksheet contained the raw response data for those listeners. Analysis of data was performed at iBiquity and included in this report as a series of tables. Data was aggregated from all 6 experiments, and placed into 1 excel workbook. All mean opinion scores are presented, as well as the confidence intervals for each score. The format of these tables was designed by iBiquity and accepted by the NRSC Evaluation Working Group.

Appendix E - Exhibit 1

NRSC AM AUDIO SUBMISSION LISTING

ARTIST	ALBUM TITLE	**SONG TITLE**	**ASIN NUMBER**	TIME	**Analog Pre-processor settings**	**Digital Pre-processor settings**
Bach	Brandenburg Concerto #5, D Major	Allegro	B000003CZT	9:02-9:19.39	Fine Arts	2B Classical
Bizet	Carmen		B0000007DT	0:48-1:05.93	Fine Arts	2B Classical
Eric Clapton	Best of Eric Clapton	Change the World	B00001U03Q	0:50-1:11	Music Heavy	Rock Open
Paula Cole	Harbinger	Happy Home	B000002N2I	0:40-0:59.912	Music Heavy	Rock Open
Crosby, Stills, Nash, & Young	Looking Forward	Sanibel	B000021XQS	2:12-2:35.53	Music Heavy	Rock Open
Debussy	String Quartet in g minor	Anime et tres decide	B000001GNA	1:43-2:04.25	Fine Arts	2B Classical
Earth, Wind and Fire	Greatest Hits	Let's Groove	B00000FC5H	2:26-2:50.18	Music Heavy	Rock Open
Donald Fagen	The Nightfly	I.G.Y	B000002KXV	2:25-2:51.347	Music Heavy	Rock Open
Fleetwood Mac	Tango in the Night	Big Love	B000002L9Y	0:23-0:44.163	Music Heavy	Rock Open
Amy Grant	Heart in Motion	Baby, Baby	B000002GJB	0:19-0:44.043	Music Heavy	Rock Open
Handel	Messiah	Hallelujah	B000003CY	0:07-0:31.594	Fine Arts	2B Classical
Jaques Ibert	Summertime Music for Oboe	Entr'acte	B000000A9T	0:33-0:56.878	Fine Arts	2B Classical
Moulton Labs	CriticalListening Excerpts	Kyoko Saito	N/A	Cut 3	Fine Arts	2B Classical
REO Speedwagon	Hi Fidelity	Keep on Loving You	B0000025KF	2:13-2:33.568	Music Heavy	Rock Open
Carlos Santana	Supernatural	Smooth	B00000J7J4	3:27-3:50	Music Heavy	Rock Open
Lisa Stansfield	Lisa Stansfield	The Real Thing	B000002VNO	3:09-3:31.236	Music Heavy	Rock Open
Stravinski (Berstein conducts)	Firebird	Track 5	B000001GNV	0:23-0:44.163	Fine Arts	2B Classical
Randy Travis	A Man Ain't Made of Stone	A Heartache In the Works	B00001QGNB	0:54-1:16.366	Music Heavy	Rock Open
Suzanne Vega	Nine Objects of Desire	Caramel	B000002G60	0:31-0:48.041	Music Heavy	2B Classical
Ballet Woman	Voice Over from WTOP				Music Heavy	Rock Open
Camera	Voice Over from WTOP				Music Heavy	Rock Open
From Richmond	Voice Over from WTOP				Music Heavy	Rock Open
Riverdance	Voice Over from WTOP				Music Heavy	Rock Open
Imagine	Voice Over from WTOP				Music Heavy	Rock Open
WTOP Theme	Voice Over from WTOP				Music Heavy	Rock Open
FemaleA1	Austen	Northanger Abbey		CD1; track 2	News	TV 5B-News
FemaleB2	Brown	The Switch		CD3; track 5	News	TV 5B
FemaleC10	Scottline	The Vendetta Defense		CD3; track 6	News	TV 5B
MaleA1	Coonts	Hong Kong		CD3; track 2	News	TV 5B
MaleB4	Glenn	John Glenn: A Memoir		CD1; track 1	News	TV 5B
MaleC5	Grisham	A Painted House		CD1; track 1	News	TV 5B

Appendix E - Exhibit 2

Procedure for Editing and Leveling Sound Samples

Editing Sound Samples

When editing a sound sample, the goal is to create an envelope at the beginning and end of the wave file that contains no noise preceding or following the desired music or speech sample. Elimination of noise at the beginning and end of all sound samples is crucial because any noise that is present can serve as a cue that can be used to identify samples during testing.

Procedure for Editing Sound Samples

The wave file to be edited is first opened in Cool Edit Pro. The beginning of the waveform is magnified so that it is possible to distinguish between the desired sample and any noise or silence preceding it. All noise or silence preceding the desired sample is deleted from the wave file. Next, the end of the waveform is magnified so that it is possible to distinguish between the desired sample and any noise or silence following it. Any noise or silence following the desired sample is then deleted. Once this has been done, it is necessary to listen to both the beginning and end of the wave file to ensure that all of the noise and silence surrounding the desired sample has been removed and to ensure that none of the desired sample was cut off by the editing that was done. If all of the noise has been removed and none of the desired sample was cut off, then the wave file is saved and editing is completed. If the wave file does not meet these requirements, the changes are undone and the editing process is repeated.

Leveling Sound Samples

In subjective testing, it is essential to ensure that all sound samples are level because any leveling differences that may exist could potentially serve as a cue to identify samples during testing. As a rule, music and speech samples are considered "level" when they sound equal in volume, as determined by a subjective listener. In other words, when two leveled samples are played back-to-back, the listener should not feel the need to adjust the volume from one sample to the next.

It is important when leveling sound samples to always level to the signal rather than to the noise. If samples are leveled to the noise, any noise that may be included in the signal (for instance, noise created by IBOC) could potentially be hidden. Consider the case where two samples were being leveled, one which has IBOC On and is noisier and another which has IBOC Off and is less noisy. If one were to level to the noise, the IBOC-On signal would be de-amplified (since that sample is noisier) and, in doing so, the signal would also be de-amplified. This may cause the signal to sound less noisy and hide the effects of IBOC. In contrast, by leveling to the signal, this problem is eliminated.

When leveling, it is also essential to never amplify sound samples. Amplifying samples results in amplification of any audio impairments that may exist in the sound sample, regardless of whether the sample has IBOC On or Off. The overall sound quality of both IBOC Off and IBOC On samples will be more favorable when impairments are not amplified. Thus, samples should always be de-amplified so that they are level with the softest sound sample.

Procedure for Leveling Sound Samples

When leveling a group of samples, a subjective listener first listens to each sample to determine which sample is the softest. All other samples will be de-amplified to match the level of the softest sample.

Once the softest sample is identified, the listener listens to the level of the other samples again. Samples will generally divide into similar groupings, based on the pre-processor settings used during the recording process. These groupings are referred to as “bands.” The loudest samples are put into the highest band, the softer samples into the softer bands, and the softest samples into the softest band. As many bands as are needed are created. Samples within each band should be approximately the same level.

For each band, the listener listens to the samples and makes sure they are level with each other. If they are not level, the louder samples in the band are de-amplified so they are level with the softer samples in the band.

Once the samples within each band are level, the listener proceeds to level across bands, starting with the loudest band. The loudest band is de-amplified so it is level with the softest band. Then, the second-loudest band is de-amplified so it is level with the softest band (Note: The decrease in decibel level necessary to achieve this will be less than the decrease in decibel level necessary to de-amplify the loudest band to the level of the softest band). The remaining bands are de-amplified (from loudest to softest) to the level of the softest band.

Finally, the listener should listen to all samples to ensure they are all the same level. If an individual sample is louder than the rest of the samples, it is de-amplified so it is level with the others. If an individual samples is softer than the rest of the samples, any de-amplification to this sample is undone and it is de-amplified again so that it is level with the other samples.

Appendix E - Exhibit 3

Audio Sample Selection: Field Test Data Analysis Procedures

For the purpose of characterizing the performance of its digital receivers in the field, iBiquity developed a custom data acquisition system, which includes a GPS receiver, spectrum analyzer, video camera and a multitrack digital audio recorder. A personal computer running field test data acquisition software, known as *The Collector*, controlled and coordinated the data capture and storage from the digital radio and test equipment. For the AM field testing, the primary data gathered by *The Collector* were:

- GPS location and time (latitude/longitude coordinates plus GMT seconds in the day)
- Spectral plots of the AM band within several adjacent channels of the IBOC test transmission
- SMPTE timecode data from the digital audio recording system
- Telemetry data from the digital receiver
- PC time stamp and test operator hotkey data

To facilitate data analysis, iBiquity developed *iVIEW*, a post-processing software tool that interpreted data files created by *The Collector*. *iVIEW* provided VCR-like playback of drive test data, showing captured spectrum, drive route progress, SMPTE time code of recorded receiver audio, radio performance parameters and hotkey comments. *iVIEW* also provided utilities for mathematical processing of the raw field test data. These utilities operate on portions of the spectral data to calculate powers and desired-to-undesired (D/U) ratios for signals of interest.

iVIEW capabilities for searching and exporting field test data include

- a conversion engine for processing and loading *The Collector* files into a relational database,
- a parametrically-specified data search tool and
- export modules that can extract and process user-specified field information from the test files and export this processed information to delimited text files.

Figure 1 is a screen shot of the *iVIEW*'s main screen.

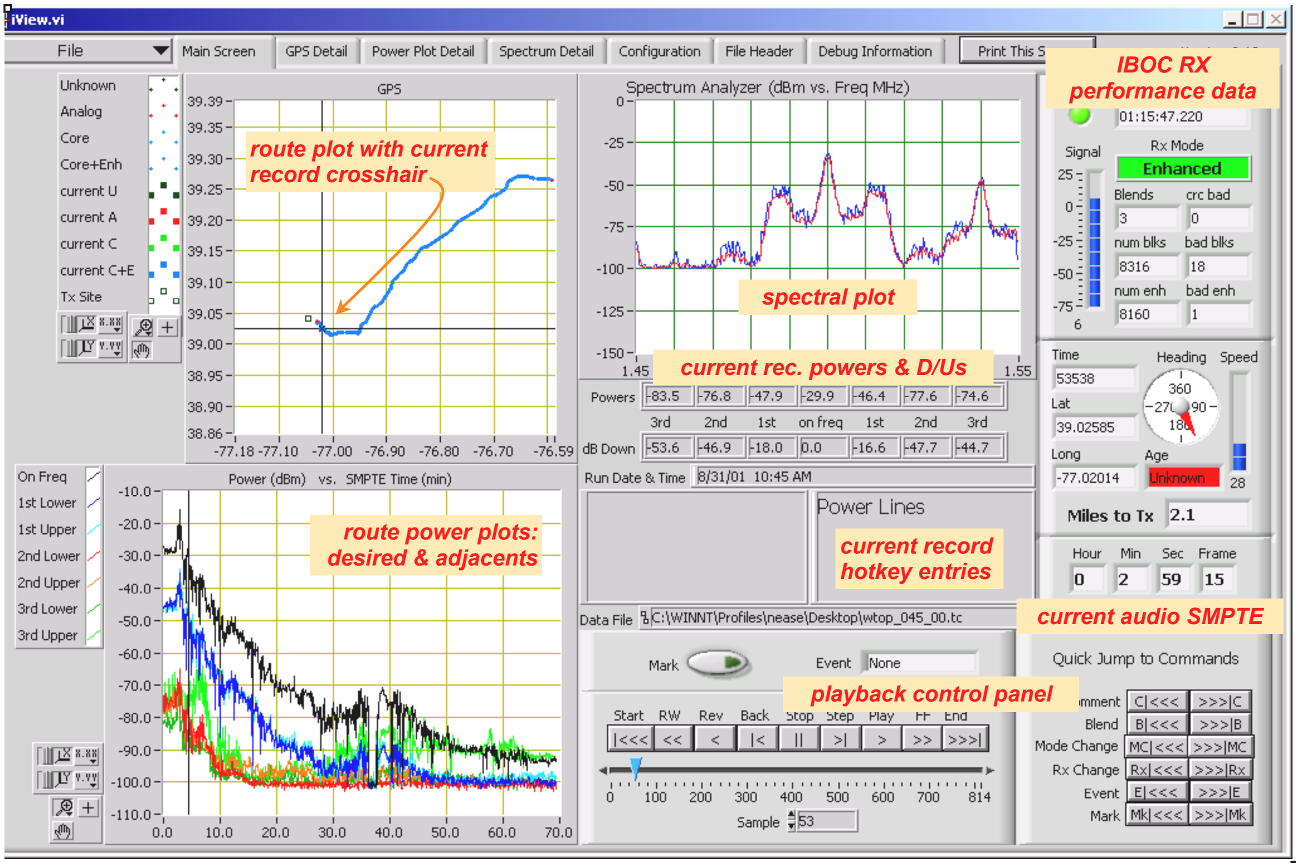

Figure 1: Annotated *iVIEW* Main Screen

To subjectively evaluate field test performance, it was necessary to locate field and operational conditions of interest among the collected data. Once these conditions were identified, the corresponding recordings of IBOC and analog AM receiver audio were examined to determine whether they contained audio segments suitable for subjective experimentation. For Hybrid AM IBOC, the conditions of interest included:

1. Significant 1st and 2nd adjacent channel interference
2. Whole or partial shielding by Grounded Conductive Structures (GCSs)
3. Proximity to powerlines
4. Powerline re-radiation of the AM signal
5. Electromagnetic interference (EMI)
6. Occurrences of IBOC audio mode transitions from enhanced to core and from digital to analog
7. Skywave interference (night performance)

Except for IBOC audio mode transitions, all performance audio samples were selected from within the IBOC receiver's digital audio coverage area. Each of the following sections describes the methods by which subjective audio samples corresponding to specific conditions were identified.

Adjacent Channel Interference
Searches for single 1st, single 2nd and combination adjacent channel interference conditions were done using *iVIEW* and Microsoft Excel. For each field test radial, all data files corresponding to that radial were loaded into *iVIEW* in append fashion, from first to last in direction of travel. Using *iView's* export function, the field test data analyst creates a tab-delimited text file (with ASCII linefeeds and carriage returns) to place each measurement record on a separate line. Each record (text line) included a record index, time, SMPTE timecode, distance to the transmitter, latitude/longitude, and the field intensities of the lower 1st and 2nd adjacent channels, the desired channel and the upper 1st and 2nd adjacent channels. Each record also contained IBOC receiver mode information and any hotkey data entered during that measurement cycle. This tab-delimited text file for the complete radial was opened using Excel and parsed by specifying ASCII tab characters as the column delimiters. Next, the desired and undesired signal levels were averaged over a three record window and plotted along with the radio mode and distance from the transmitter against elapsed drive time for the radial. Figure 2 shows an example *strip chart* plot for radial 270 of station WWJ. From each of the radial strip charts, the data analyst identified the stretches along radials exhibiting the highest levels of adjacent channel interference where the IBOC radio was in a digital reception mode. After graphically identifying candidate interference regions, the analyst created a list of SMPTE time codes for candidate audio that includes corresponding D/U ratios for the upper and lower 1st and 2nd adjacent interferers. The audio editing team selected as many as possible usable audio samples from the candidate audio. The D/U ratio information was coded into the audio sample's *.wav file name using this convention:

Adjacent Channel D/U ratio identifier = **ABCD**, where

A ≡ the lower 2nd adjacent D/U ratio in dB,
B ≡ the lower 1st adjacent D/U ratio in dB,
C ≡ the upper 1st adjacent D/U ratio in dB,
D ≡ the upper 2nd adjacent D/U ratio in dB, and "+" and "- " are explicitly used, except where D/U = 0 dB.
"X" connotes insignificant interference, that is a D/U ratio > +15 dB.

For example, a sample for which

Lower 2nd D/U = 14 dB,
Lower 1st D/U = 0 dB,
Upper 1st D/U = 19 dB, and
Upper 2nd D/U = -8 dB

includes the alphanumeric "+14x0-8 in its *.wav file name.

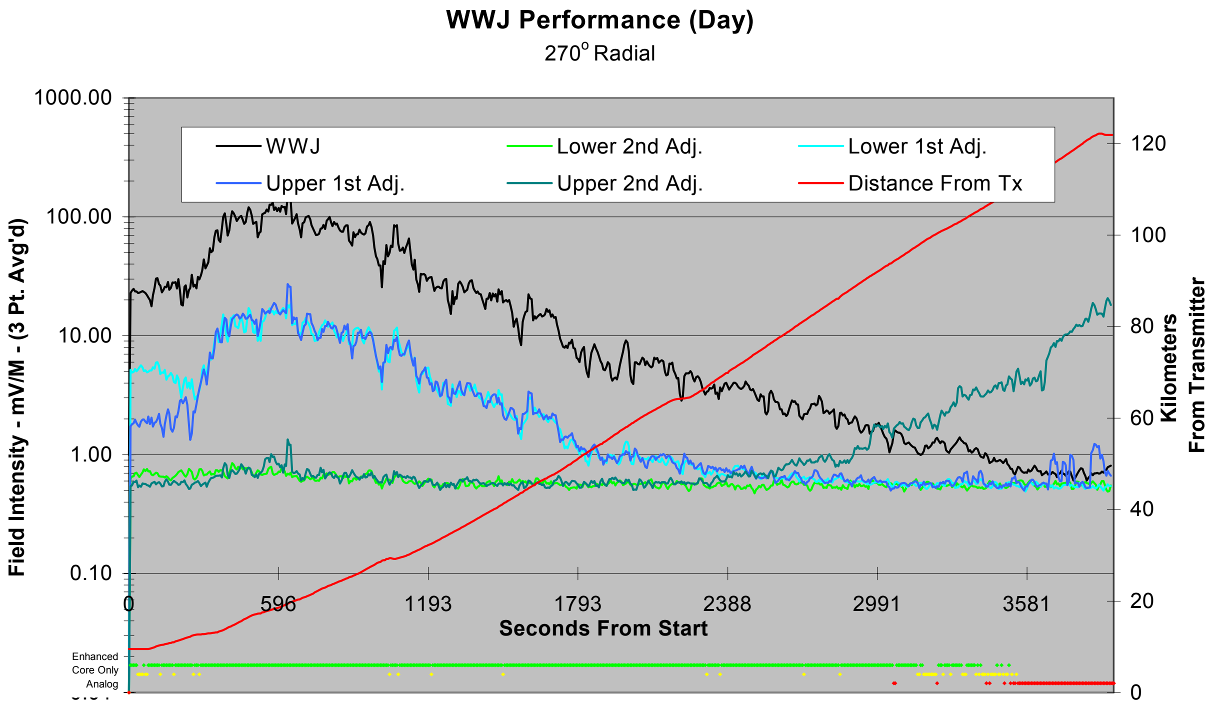

Figure 2: Radial Strip Chart

Grounded Conductive Structures and Overhead Powerlines

During field testing, test operators noted GCS and overhead powerline incidences using *The Collector*'s hotkeys. During data analysis, the test data files were searched for the hotkey entries "bridge", "overpass", "underpass", "overhead sign" and "powerline." In each instance, the corresponding audio recordings from the Delphi and Pioneer receivers were checked for audible indications of GCS or powerline effects on reception. If analog receiver degradation could be heard and the IBOC receiver remained in digital mode, the audio was flagged as candidate audio for subjective tests. The audio editing team selected as many as possible usable audio samples from the candidate audio.

Powerline Re-radiation

Areas in which powerline re-radiation might occur were identified by test operator observation and knowledge of the test area. As indicated by the NRSC, powerline re-radiation effects were more likely to occur in the situations where the test van is traveling near and parallel to high-tension power lines (with a grounding skywire) that also happen to run within a couple of miles of the IBOC transmitter. These areas were identified for each station. Data analysts reviewed the *analog* receivers' audio recordings to detect the signal fading characteristic of destructive interference between the AM groundwave and a re-radiated signal from the power lines. Where such interference is evident, audio samples from both analog and IBOC receivers' recordings were extracted for subjective evaluation.

EMI

The primary method of identifying electromagnetic interference conditions was the comprehensive review of the analog receiver audio recordings to identify audio impairments – e.g., hum, buzzing and crackling – characteristic of EMI channel conditions. In this manner, iBiquity engineers reviewed and annotated completely the analog receiver field test audio. Using SMTE timecode correlation, engineers ascertained which EMI channel conditions occur within the IBOC digital coverage area. Where EMI and digital coverage coincide, the audio editors extracted subjective audio samples from both the digital and analog receivers for subjective testing.

IBOC Audio Mode Transitions

Using *iVIEW*'s export utility, a tab-delimited ASCII file containing test record indices, SMPTE timecodes and IBOC reception modes was created for each station radial. Using Excel, data analysts examined each file to locate and classify the IBOC receiver's audio mode transitions between enhanced, core and analog states. The sequence of audio mode changes in a test audio segment defined the type of transition. Some examples of mode transition type were core-to-analog, core-to-enhanced and enhanced-to-core-to-enhanced, coded CA, CE and ECE, respectively. The audio editing team reviewed the corresponding audio files to locate suitable subjective audio representing each audio mode transition type. Audio samples from the IBOC and both analog receivers for each identified sample were submitted for subjective testing.

To facilitate data analysis in this test, the *.wav file name of each subjective audio sample included coding to indicate audio modes represented in the sample.

Skywave

iBiquity engineers reviewed the analog receiver audio for each nighttime field test in order to identify AM skywave interference. Skywave interference was typified by the simultaneous, audible reception of co- and 1st adjacent stations along with the desired station. Examples suitable for subjective testing were identified within the IBOC receiver's nighttime digital coverage area. Samples from the IBOC and both analog receivers were submitted for subjective testing.